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THE CASTING OF CLAY WARES

BY

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CONTENTS.

	Page.
Introduction	5
Purpose of the report	6
Ware as formed by the plastic and casting processes	6
Slips	7
General requirements	7
Single cast	7
Solid cast	8
Overcast	8
Comparison of requirements	9
Properties controlled by colloidal content	9
Relation of colloidal content to plasticity and casting properties	10
Method of controlling colloidal content	12
Effect of salt additions and its measurement	12
The viscosimeter	12
Measurements by the viscosimeter	13
Casting behavior with different salt concentrations	15
Selection of clays	16
Effect of temperature	18
Factory practice in preparation of slip	18
Different methods of preparing the slip	18
Proposed method of preparing slip	19
Variations to be avoided	20
Use of scrap	20
Molds	21
Design and use	22
Making of ware	23
Burning of ware containing soluble salts	25
Publications on mineral technology	25

ILLUSTRATIONS.

		Page.
FIGURE 1.	Cross section of lid and mold	8
2.	Cross section of wash-down closet	9
3.	Flow viscosimeter	13
4.	Curves showing effect of sodium carbonate as measured by viscosimeter readings	14
5.	Effect on viscosity of varying the proportions of clays in a slip	17
6.	Cross section of sink and of core mold	23

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THE CASTING OF CLAY WARES.

By TAINE G. MCDOUGAL.

INTRODUCTION.

One of the investigations being conducted by the Bureau of Mines deals with the increase of efficiency and the prevention of waste in the utilization of the mineral substances necessary to the ceramic industry. Results of an investigation of kaolin and feldspar in the southern Appalachian States were published in Bulletin 53.[a] This paper deals with the casting of clay wares.

Casting has for years been successfully employed by European potters as a method of forming clay wares, but in this country results with the process, although successful in some instances, have been so varying and uncertain that relatively little progress has been made. Some potteries, using formulas and following methods successfully used by another pottery, have found themselves unable to duplicate the results that had been obtained. Other potteries, using these formulas and instructions as a basis for more extensive experiments, have attained what might be termed periodic success; the clay slip used working well and resulting in sound ware for a period of days or weeks, and then, although no change in material or process has been knowingly made, something intangible and unexplainable happens, resulting in poor slip and bad ware. At other plants, more especially those making the thinner, lighter wares, casting has been successfully applied and is in daily use.

The variation and uncertainty in the results obtained by the different plants are, in the author's opinion, directly traceable to the following causes:

(*a*) Where no soluble salts are employed, variations arising from the use of slips varying in clay content and in the proportion of dry scrap clay used;

(*b*) Improper preparation of the slip[b] to be cast, often a result of

[a] Watts, A. S., Mining and treatment of feldspar and kaolin in the southern Appalachian region, 1913, 170 pp.

[b] In this report slips are classed as (1) "clay slips," in which the solid material has been derived from clay alone or a mixture of clays, and as (2) "body slips," in which the solid material is a mixture of clay, feldspar, and flint.

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erroneous adoption of recipes governing the use of sodium carbonate and sodium silicate, or other chemicals classed generally as "soluble salts";

(*c*) Insufficient regard for the relatively narrow limits within which the properties of the slip used may be allowed to vary;

(*d*) Poor selection of the china and ball clays from which the clay content of the compounded bodies is derived;

(*e*) Improper condition of the mold.

PURPOSE OF THE REPORT.

Casting, as a rule, is undertaken by potteries that are at the time using one of the plastic processes. The object of this paper is to point out, in the light of experiments and factory observations, the difference in procedure necessary and the precautions advisable when changing from a plastic to a casting process. The paper is addressed especially to the practical potter, and the matters considered are discussed with regard to factory rather than laboratory problems, only as much theoretical discussion being given as is deemed necessary to a better understanding of the practical application. The more familiar one becomes with the questions involved the more one realizes that each manufacturer must work out his individual problems. It is hoped that this report may enable the potter who is using or intends to use the casting process to solve successfully the difficulties usually encountered. An effort has been made to point out the variable factors that govern the behavior of a casting slip and the wares cast from it. The author trusts that this discussion will enable the reader, with the help of his practical knowledge of plant operations, to carry out intelligently a series of experiments that will show how a slip best answering the requirements of the particular ware to be cast can be produced.

WARE AS FORMED BY THE PLASTIC AND CASTING PROCESSES.

The condition of a freshly made cast piece will be compared with that of one made by a plastic process.

A piece of pottery that has just been formed in the mold by pressing or jiggering contains throughout its thickness practically the same proportion of water, say 25 per cent, that it did on leaving the pug mill. It is, therefore, in a condition that favors even drying. This initial condition is, of course, immediately altered as drying begins through contact of the two surfaces with a plaster mold or with the air. The more evenly the drying can be maintained, the safer will it proceed.

Conditions favoring even drying, although not so important in the thinner wares, are extremely necessary in those of heavier and more intricate design.

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In the case of a piece just formed by the casting process the slip, containing from 30 to 60 per cent of water, has been standing in the mold for the length of time necessary to form the thickness of cast desired. Consequently that surface of the ware which is adjacent to the absorbent plaster mold has had time to begin to dry, the drying being retarded, of course, by the passage of water through to the mold from the slip in contact with the opposite surface. The surface immediately in contact with the slip has still practically the same water content as the slip itself. With this condition existing, the two surfaces of the piece have a very different water content, so that uneven drying, subsequent straining, and resultant cracking of the piece may be expected.

It is the aim, then, in producing a cast piece to approach as nearly as possible to the more desirable conditions normally obtained in a piece formed by the plastic process. And to obtain this end it is necessary to manipulate intelligently the properties of the slip to be used.

SLIPS.

GENERAL REQUIREMENTS.

The heavier the ware to be cast and the more intricate its design the more important become the correct properties of the slip to be used and their maintenance within proper limits. Let it be understood, however, that once these are obtained the potter, by using reasonable care, can keep within the allowable limits of variation, and by keeping within them can have slip of more constant properties and within better control than is obtained in factory practice with clay as pugged for the jiggerer or presser.

The requirements exacted vary, then, with the character of the ware to be cast, and this in turn makes it necessary to vary the method of forming the cast product. The methods of formation may be classed as follows: Single cast, solid cast, and overcast.

SINGLE CAST.

Usually the ordinary single cast does not have to be more than one-quarter to one-half inch thick. The single cast is the most widely used method of forming wares, as it is applicable in the manufacture of many different articles of comparatively light construction. The slip is poured into an absorbent plaster mold, allowed to stand for five minutes to an hour, according to the particular slip used and the thickness of cast desired, and then drained off, leaving a clay form of the shape and thickness desired adhering to the mold.

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SOLID CAST.

In the solid cast the ware is formed between two adjacent and usually parallel walls of a mold, the slip casting on both walls until the two single casts thereon unite to form one solid cast. If, as shown in figure 1, a massive rim or other unnecessarily heavy part is to be formed, this can be drained before the two single casts at this particular place are united, leaving what is termed a hollow cast. The slip in this instance must be mechanically thin enough to drain cleanly from the small inclosed space.

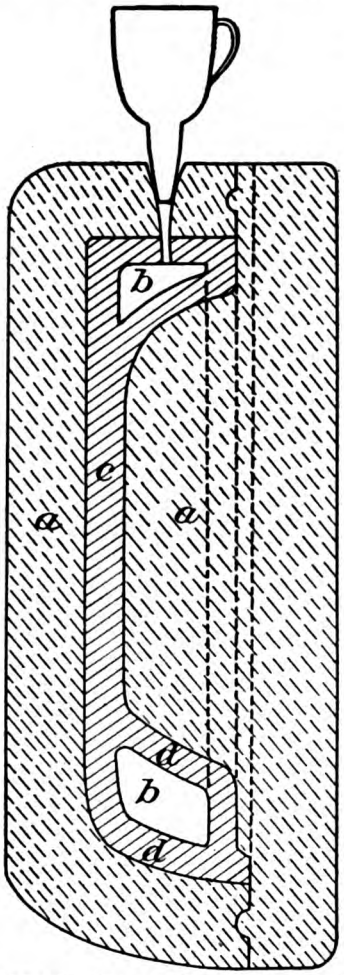

FIGURE 1.—Cross section of lid and mold. *a*, *a*, Plaster molds; *b*, hollow cast from which slip is drained; *c*, solid cast; *d*, single cast.

OVERCAST.

The third method is known as overcasting. Bourry[a] states that if the object to be cast must have rather a large thickness it is preferable to make the pouring in two or three times, allowing the body to harden a little between each operation. This process is used in making thick or complicated designs, such as are used in making sanitary porcelain.[b] In casting the bowl shown in figure 2 the trap *a*, a combination of single and solid casts, and the foot *b*, a solid cast, are cast, removed from their molds, covered with damp cloths, and allowed to stand overnight. The trap and foot are then placed in position, as shown in the figure, in an assembly mold which, with a core to form the single cast d_2 and the solid cast d_1, forms the outer shell of the closet. The assembly mold is filled with slip, which casts the walls *d* and at the same time softens and incorporates the trap *a* and the foot *b*. Of course the slip also casts to some extent on the clay trap and foot. The result is one solidly cast piece, which is drained of excess slip through *e* and *f*. The rim *c* is a separate single cast, which is "stuck on," in the position shown, by a "roll" of plastic clay.

[a] Bourry, Emile, Treatise on ceramic industries, a complete manual for pottery, tile, and brick works, 1911, p. 231.

[b] See Kirk, C. J., Use of the casting process for large clay wares: Trans. Am. Cer. Soc., vol. 15, 1913, pp. 573–584.

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COMPARISON OF REQUIREMENTS.

The casting of these three forms, the single cast, solid cast, and overcast, requires progressively more carefully prepared slips; that is, a more variable slip may be used for a single or solid cast, whereas the requisite properties of a slip for successful overcasting are indeed exacting. There is yet to be found a body slip suitable for overcasts that does not make an exceptionally successful single or solid cast. On the other hand, it is possible to obtain a satisfactory single or solid cast from a slip which would completely fail if tried in an overcast. The overcast is, therefore, an excellent criterion whereby to judge the working properties of a slip for use in the less exacting single or solid casts.

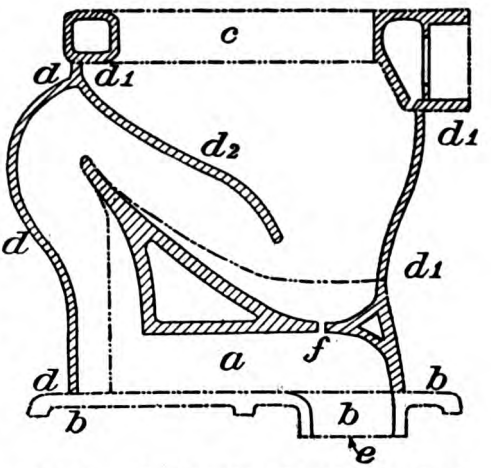

FIGURE 2.—Cross section of wash-down closet.

PROPERTIES CONTROLLED BY COLLOIDAL CONTENT.

As a fundamental knowledge of what governs or determines the properties that make a slip adaptable to the different kinds of casts as above outlined is essential, a short discussion of the theory involved is given here.

Mechanically, the mineral particles of a clay or body slip may be graded from coarse (those passing 120-mesh lawn) to those so small that they are really no longer merely present as particles in suspension, but are actually in a state of partial solution in the water. Colloids, more correctly designated as particles in a collodial state, is the name given to these ultrafine particles, so small that they have lost the characteristics typical of their coarser state, and yet not finely divided enough to be regarded as truly in solution.

As the size of the particles varies continuously from coarse, 120-mesh, to ultrafine, it is obvious that any division between those to be termed colloidal and those termed noncolloidal must necessarily be arbitrary. The reader is referred to Technologic Paper 23[a] of the United States Bureau of Standards for a technical discussion of colloids by Ashley.

Ashley states that the plasticity of a clay is directly determined by the character and amount of the colloid matter in the clay. And

[a]Ashley, H. E., Technical control of the colloidal matter in clays, 1913, 118 pp.

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so, too, are the casting properties of a clay slip fundamentally determined by this same colloidal content. To quote Ashley:[a] "Colloids exist in two characteristic forms—(1) as a homogeneous suspension in a liquid, called a 'sol,' and (2) as a continuous jelly with pore walls (and pores) filled with a liquid, called a 'gel.'"

RELATION OF COLLOIDAL CONTENT TO PLASTICITY AND CASTING PROPERTIES.

A clay or compounded body high in gel is said to be plastic or in the extreme case sticky, whereas one relatively low in gel, either because of a total lack of colloidal particles or because the gel has either been "set" or converted to the sol in the manner discussed on a subsequent page, lacks plasticity and is said to be "short." A clay gel may be "set" by being exposed to heat. Exposure to the heat of the drying room will set the gel, with the result that the dry clay scrap loses its plasticity, a loss which it fully recovers only after long blunging or artificial treament.

By choosing the proper clay, or proper combination of clays with the other mineral ingredients, usualy feldspar and flint, the proportion of collodial material may be controlled, whereas the conversion of sol to gel, or gel to sol, can be controlled by adding certain chemicals to the blunged body. If collodial material is present, no matter what its initial form, the operator is able to manipulate within limits the plasticity of a clay body by controlling the relative proportion of gel to sol. It may occur to some that this fact could be applied to making kaolins more plastic and in this way the necessity of using any ball clay could be avoided. The artificial plasticity can not, however, wholly replace that obtained through ball clays. The gel of those china clays with which the author has had experience lacks the bonding strength typical of ball-clay gels. In other words, the china-clay gel can be increased in quantity but not improved in quality.

In preparing many natural clay bodies and most compounded pottery bodies every effort is made to furnish the turner, jiggerer, or presser with a body as plastic as can be had with the material at hand, although there are some natural clay bodies whose gel content is too high for successful plastic use. For example, a very plastic clay mined near Clayton, Wash., when used for stoneware gives trouble from excessive shrinkage, and careful drying must be practiced. The same clay, when used for terra cotta, must be preheated (to partly set the gel) in order to obtain a workable body. Illinois joint clays[b] furnish another example. Aging or weathering, in the case of fire clays, and careful pugging and aging in damp cellars in the case of

[a] Ashley, H. E., The colloid matter of clay and its measurement: Bull. 388, U. S. Geol. Survey, 1909, p. 14.

[b] Bleininger, A. V., and Layman, F. E., A method of making possible the utilization of an Illinois joint clay: Trans. Am. Cer. Soc., vol. 11, pp. 354–364.

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compounded bodies—Minneman[a] reports the use of magnesium sulphate for restoring plasticity to dry scrap clay—are practiced in furthering the development of gel colloids, and consequently increasing the plasticity. In working by the plastic process, then, the problem in most cases is that of converting sol to gel.

For casting purposes, on the other hand, most natural clay bodies and nearly all compounded bodies, except, perhaps, a few that contain little or no ball clay and are usually so composed for the especial purpose of casting, contain too great a preponderance of the gel and are too plastic for successful use in casting. The author, in casting a red burning ferruginous shale used in the manufacture of roofing tile, found it necessary to diminish the gel by adding a soluble salt. The problem in casting, then, is in most cases to diminish the gel.

If an attempt were made to cast any but the thinnest ware with slip from a body which was plastic enough to be used in turning, jiggering, or pressing, several difficulties would be encountered.

To begin with, the slip would contain about 60 per cent of water, an abnormal amount for the plaster mold to absorb, as the same body prepared for the presser would contain about 25 per cent, or for the jigger about 30 per cent, of water.

As the slip casts to the mold, the layer formed, as it grew in thickness, would offer an increasingly difficult barrier to the water on its way to the mold. This fact would seriously limit the thickness of the cast.

That surface of the layer adjacent to the mold would, after the desired thickness of cast had been obtained and the excess slip drained, be so far advanced toward drying, as compared with the opposite surface from which the excess slip had just been drained, that uneven drying and cracked ware would result. With most slips of this kind it is impossible to get a clean-cut separation of excess slip from a part that is really cast; a layer of slip always sticks or hangs to the latter.

As will be explained later, with a reduction in the proportion of gel to sol, it is possible to reduce the water content (in a usual case from 60 per cent to 28 per cent) of a given clay or body slip to practically the same proportion that would be required to work the same clay or body in the plastic condition and still have it as fluid as was the original slip (high in its proportion of gel), with its higher water content.

Changing gel to sol eliminates the bulky, plastic property of the slip, and the ware cast from the altered slip is "open" enough to permit a freer passage of water to the mold while the piece is being cast.

[a] Minneman, J., Note on the restoration of plasticity to scrap clay: Trans. Am. Cer. Soc., vol. 16, 1914, pp. 96, 97.

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Because the water is allowed a freer passage the division is sharper between the part that is actually cast, and is adhering to the mold, and the excess slip which is to be removed by draining. A cleaner cut drain is obtained, leaving a cast piece of ware whose two surfaces—the one that was adjacent to the slip and the one that is in contact with the plaster mold—differ less in moisture content.

METHOD OF CONTROLLING COLLOIDAL CONTENT.

When the pieces to be cast are of simple design and not very thick, the three difficulties mentioned may be diminished, often sufficiently, by reducing the ball and china clay contents to a minimum and by using dry scrap in which the gel has been partly set by the drying-room temperature.

For the more exacting uses, however, a more satisfactory and positive method of controlling the colloidal content is necessary. This is obtained by adding to the slip certain soluble salts or electrolytes.

Although a great number of salts have such an effect on clay, only two, sodium carbonate (Na_2CO_3) and sodium silicate (Na_2SiO_3), are discussed here. These are commercially available and the ones most commonly used. Sodium carbonate is obtained commercially as crystalline sodium carbonate of the formula $Na_2CO_3.10H_2O$, which contains about 31.5 per cent dehydrated carbonate. Sodium silicate is obtained as a water solution, usually at 40° B., which corresponds to a specific gravity of 1.375, that contains about 41.6 per cent dry silicate.

EFFECT OF SALT ADDITIONS AND ITS MEASUREMENT.

On adding a small quantity of a concentrated solution of sodium carbonate to slip as taken from the blunger and stirring it thoroughly, it will be found that the slip becomes very thin, and that the solid particles seem to have shrunk and to move much more freely in the water suspending them. As more of the solution is added, the particles tend to settle to the bottom. On continued additions with constant stirring, however, the slip begins to rethicken and may become more viscous than it was when taken from the blunger.

THE VISCOSIMETER.

In order to measure this variation in freedom of movement of the body particles that results on adding successively increasing amounts of certain soluble salts, the fluidity or the viscosity of the slip is measured by means of a simple device called the "flow viscosimeter" (fig. 3).

The viscosimeter is a brass cylinder 2 inches in diameter and 6½ inches high, and has a screw cap at each end. The bottom cap has in its center an orifice five thirty-seconds inch in diameter; the one on top is drilled and threaded to receive a hollow tube, one-eighth inch in inside diameter—the author found discrepancies in the re-

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sults obtained with two viscosimeters that differed only in the size of the air tube used—which extends into the cylinder and admits air at a constant point and thus allows the liquid slip to discharge from the orifice under a constant head. The time required for 200 c. c. (or any given volume) to flow from the viscosimeter is taken with a stop watch, and may be checked within two-tenths of a second on readings under one minute.

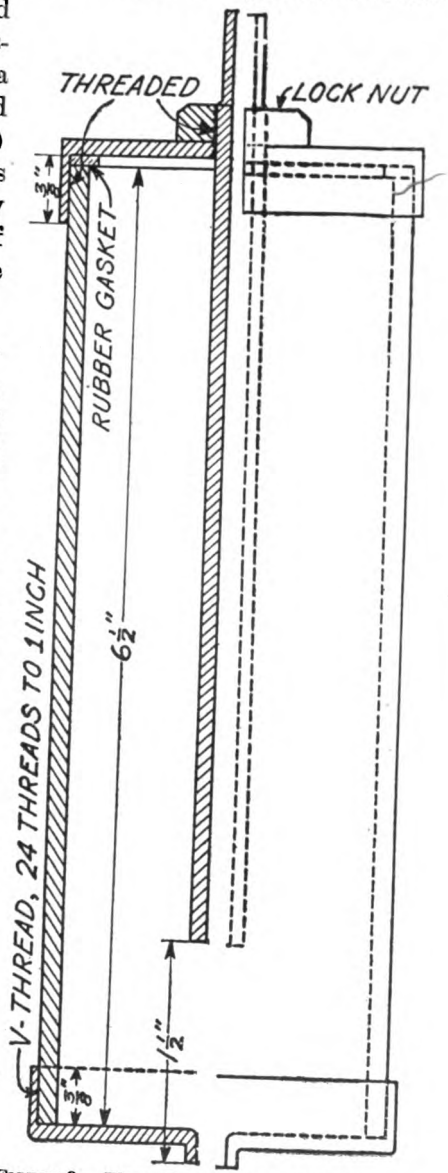

FIGURE 3.—Flow viscosimeter. At left, section; at right, front view.

MEASUREMENTS BY THE VISCOSIMETER.

In experiments with a porcelain body containing 56 per cent of flint and feldspar, 31 per cent of china clays, and 13 per cent of ball clays, three slips that weighed respectively 130.5, 136.5, and 142.2 grams per 100 c. c. were prepared. On adding to 500 c. c. volumes of the slip increasing proportions of sodium carbonate, the viscosimeter readings plotted in figure 4 were obtained.

The curves, which show that maximum thinning, indicating maximum conversion of gel to sol, is effected by adding the same quantity of carbonate per 500 c. c. regardless of the different amounts of clay in suspension, indicate that the effect produced is dependent upon the concentration of the carbonate in the water present. Curve 3 indicates a maximum point with somewhat lesser additions than in the case of curves 1 and 2, which can be explained by the fact that slip 3 contained more solid material and consequently less water (in 500 c. c. of slip), and, therefore, the concentration required for maximum effect was reached sooner.

After the point of maximum thinning effect was reached, continued additions failed to produce any noticeable change in the properties of the slip until about 3 grams had been added, when a

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reversion of sol to gel began. This, however, requires more carbonate than is permissible with regard to the behavior in the kiln of the resultant body, and is therefore of only passing interest here.

Sodium silicate gives the same thinning effect as sodium carbonate, excepting that the approach to the maximum effect attainable is more

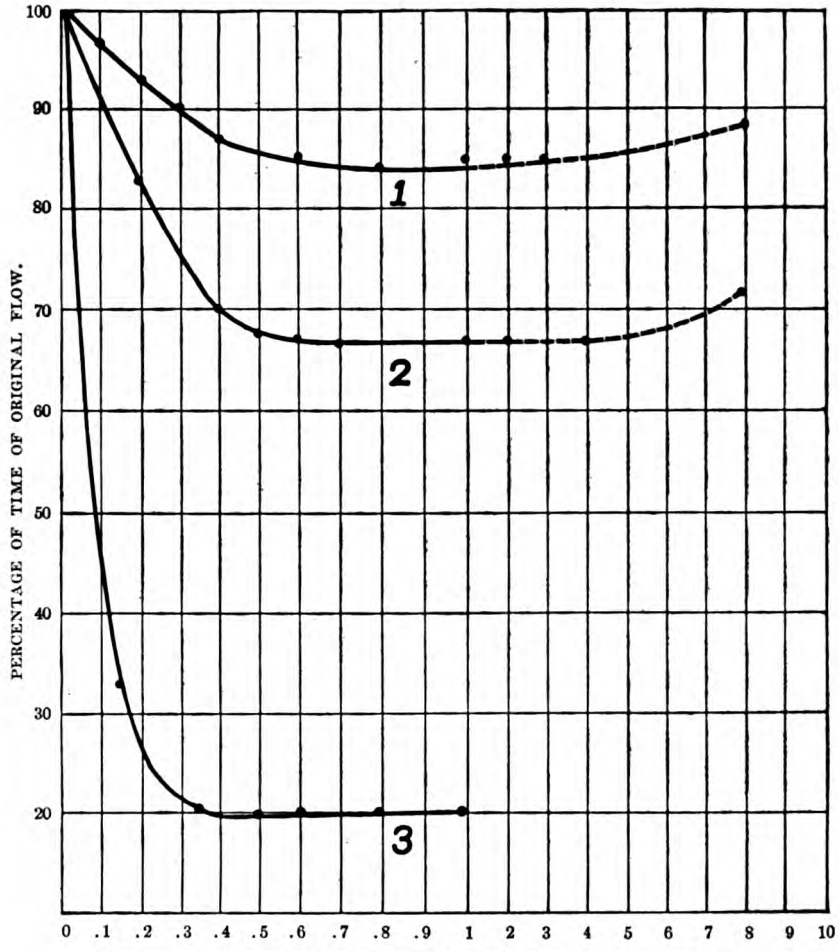

FIGURE 4.—Curves showing effect of sodium carbonate as measured by viscosimeter readings.

gradual. On the same body as used in the carbonate tests, minimum viscosity was obtained with a concentration of 0.8 grams of 40° Beaumé silicate, containing 41.6 per cent of dry sodium silicate.[a]

[a] For discussions of the effect of electrolytes on clay see: Effect of different soluble salts on a stoneware clay: Trans. English Cer. Soc., vol. 6, ——, pp. 161–170. Kerr, C. H., and Fulton, C. E., The effects of some electrolytes on typical clays: Trans. Am. Cer. Soc., vol. 15, 1913, pp. 184–192. Coats, M. A., The influence of soluble salts in a clay upon the behavior of a slip and a glaze: Trans. Am. Cer. Soc., vol. 16, 1914, pp. 162–168. Back, Robert, Effect of some electrolytes on clay: Trans. Am. Cer. Soc., vol. 16, 1914, pp. 515–546.

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It is regretted that data are not at hand to show exactly the comparative effects of carbonate alone, silicate alone, and mixtures of the two in different proportions on the same body slip.

CASTING BEHAVIOR WITH DIFFERENT SALT CONCENTRATIONS.

In order to obtain the desired ratio of gel to sol for casting, it is the practice to use sodium silicate in combination with sodium carbonate. Especially is this true where the reduction in gel content is to be carried far enough for casting the thicker wares. Should carbonate alone be used and the reduction of gel content carried to a point near maximum effect (see fig. 4) the slip, although it would cast to the desired thickness, would produce a cast lacking the bonding strength necessary to safe drying. When it is not necessary, as for lighter ware, that the gel content be reduced to so near the minimum, the gel may then furnish enough of a bond to carry the ware safely through the drying stage and to the kiln. In this case carbonates alone may be used.

To remedy this lack of bonding strength sodium silicate is introduced. Although sodium silicate reduces the gel content of the clays present, it is itself a very sticky gel colloid and furnishes the bond to replace that lost by decrease in clay gel. To use silicate alone may produce that state in the slip which it is desired to overcome, namely, a bulky gelatinous condition indicating a high gel content as introduced through the silicate.

Any clay or body slip that has too low a content of salts, that is one in which the gel to sol ratio is still too high, behaves in the mold much the same as the original slip, giving a soft cast, one hard to drain cleanly, and difficult to dry safely. A solid cast made from this kind of slip shows, if a cross section of its structure is examined, that the center was soft, and that cracking was to be expected.

Slip with the proper content of salts gives a cast that feels solid and drains cleanly, leaving a sharp line of separation between the part which is cast and the excess. The cast layer will be open enough to allow water to continue to pass through to the mold until the desired thickness of cast is reached and also will, by reason of its remaining gel content or of the silicate added or of both, possess bonding strength sufficient to insure safe drying.

A slip containing too great a concentration of salts, implying a more complete conversion of gel to sol, casts rather quickly at first and sticks in a hard layer to the walls of the mold. When a layer about one-quarter inch thick has been formed, the slip will stop casting and deposit no more clay, although allowed to stand in the mold for hours. In making the heavy solid-cast pieces with such slips a hollow cast may result; that is, the two layers, one casting from each wall of the mold, do not become thick enough to unite

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and form one continuous wall. Sometimes this hollow cast is not evident until after biscuiting and often only after the glost fire has been completed, when a bloating of the ware indicates that the piece is made up of two distinct layers. In slips containing a high concentration of salts it is very difficult to remove the hard layer of cast clay from the mold, as it adheres tenaciously. It is also difficult to keep such a slip in suspension, as settling takes place, and if a clay—for instance, an English ball clay—containing organic matter is present, a brown scum is left floating on the surface.

SELECTION OF CLAYS.

With a body of given constant composition, the effects of adding varying proportions of soluble salts in determining, through the control of gel and sol content, the casting properties of the slip have been discussed. It will now be shown how many variations and complications may arise from alterations in the proportion of the various clays which go to make up a clay body or to make up the clay content of a compounded body.

After repeated unsuccessful attempts to obtain an overcast from a body containing a total clay content of 42 per cent, of which 12 per cent was English ball clays, 15 per cent was Georgia kaolin, and 15 per cent was Florida kaolin, the viscosimeter was resorted to for a possible explanation. Some very significant relations were disclosed.

Slips, to which no salts were added, were made up from each of three clays—Georgia kaolin, Florida clay, and English china clay. Each slip, after it had been standing for several days, was passed through 120-mesh lawn cloth and brought to the same weight per unit volume (245 grams per 200 c. c.). Reduced to this basis, the Georgia gave the thinnest, the English a thicker, and the Florida the thickest slip.

Viscosimeter readings were used to obtain values of these relative thicknesses, and readings were also taken on binary mixtures of each with one of the other two.

As is shown graphically in figure 5, Georgia kaolin gives a reading of 35 seconds, English china clay one of 45 seconds, and Florida kaolin one of 100 seconds, the last reading representing the thickest clay slip, at this weight, that will flow evenly from the viscosimeter.

At first thought it would seem probable that, with a slip of English china clay having a viscosity of 45 seconds and one of Georgia kaolin having a viscosity of 35 seconds, a reading for any mixture of the two would have a value somewhere between 45 and 35 seconds. Substituting increasing quantities of Georgia kaolin for English china clay caused, however, a marked thickening, which reached a

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maximum with a mixture of about 30 per cent of Georgia kaolin to 70 per cent of English china, giving a reading as high as 100 seconds.

The addition of Florida clay to English china clay had the opposite effect, as it made the mixture thinner, a mixture of 25 per cent Florida clay and 75 per cent English china clay giving a minimum reading of less than 44 seconds.

The substitution of Georgia kaolin for Florida clay caused a thickening which was not measurable, as the mixture would not flow from the viscosimeter, at the weight of slip used, until 80 per cent was added. This proportion, 80 per cent of Georgia kaolin to 20 of Florida clay, gave a somewhat unreliable average reading of 106 seconds; one of 90 per cent Georgia kaolin and 10 per cent Florida clay gave a reading of 56 seconds.

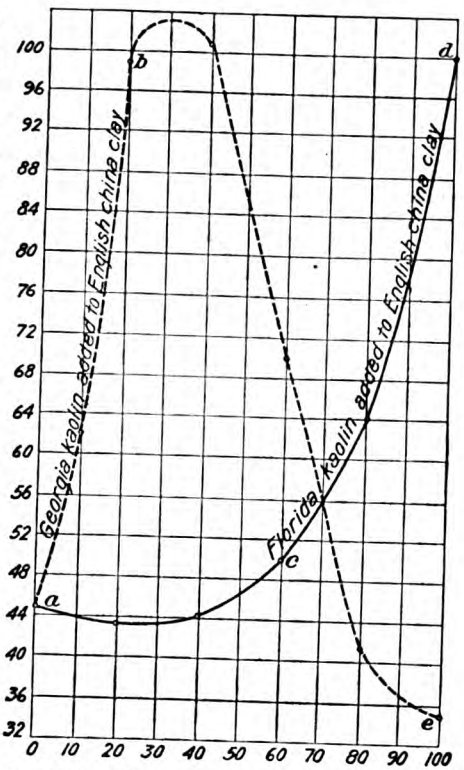

FIGURE 5.—Effect on viscosity of varying the proportions of clays in a slip. *a*, English china, viscosity 45 seconds; *b*, mixture of 20 per cent Georgia kaolin and 80 per cent English china, viscosity 99 seconds; *c*, mixture of 40 per cent English china and 60 per cent Florida clay, viscosity 50 seconds; *d*, Florida clay, viscosity 100 seconds; *e*, Georgia kaolin, viscosity 35 seconds.

The thickening, effected in each case by adding Georgia kaolin, is no doubt due to the salts naturally contained in this clay, either directly by their action on the colloidal content or indirectly by the precipitation of salts originally present in the English and Florida clays.

In general, those mixtures of china clays that are thickest in their natural condition—that is, in the slip form with water only—will require the addition of a greater proportion of salts to obtain the same gel-sol ratio as would be obtained with a lesser proportion added to another mixture of these same clays that contained originally a smaller gel-sol ratio.

Relations between the different ball clays and the ball and china clay mixtures were not investigated by the writer. However, it was found impracticable in heavy casts to use china clays alone, and the English ball clays were found to give better satisfaction than the domestic Tennessee ball clay. A limited amount, say about

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5 per cent, of Tennessee ball clay can be used with the English ball clay. Of the Tennessee ball clays, that known as No. 9 gives better satisfaction than does the No. 11 or No. 10.

EFFECT OF TEMPERATURE.

Within the temperature limits of the slip room it may be said that increasing the temperature of a slip containing salts has the same effect upon the slip as introducing more salts.

On the other hand, a decrease in temperature diminishes the effect of the salts present. In practical work it was found impossible to successfully use, at a temperature of 6° C., a 28-ounce (per pint) slip containing twenty-five one-hundredths of 1 per cent, based on the dry weight of the body, each of crystalline sodium carbonate and a sodium silicate solution having a gravity of 40° B., although at 15° C. this slip worked very well.

FACTORY PRACTICE IN PREPARATION OF SLIP.

The first step in preparing a compounded body is to blunge thoroughly with water a mixture of the several constituents—flint, feldspar, and clays—until there results a homogeneous slip; this slip is then passed through lawn usually of at least 100 mesh.

In preparing clay for a plastic process the proportion of water used may be varied considerably; it will be determined in each case by the quantity and make-up (see fig. 5) of the particular clays used in the body. Enough water, however, should be added to allow of thorough blunging without unnecessary expenditure of energy or time, and to facilitate lawning and pumping to the filter press. The use of more water than is really necessary means a decreased efficiency in blunger capacity and needless handling of excess water. In either case, however, the water content is reduced to approximately a standard proportion in the "cake" of plastic clay as it comes from the press.

An average body slip to go through this process should contain about 60 per cent of water by weight, whereas for use in casting, a slip usually should contain as low as 30 per cent. There are in general use three methods of preparing slips when, with the addition of salts, the water content is to be kept near this lower limit. A proposed method, which is shorter and more economical, is also described herein.

DIFFERENT METHODS OF PREPARING THE SLIP.

1. A blungerful of body slip containing about 60 per cent water is made up. From part of this mixture filter-press cakes, containing about 25 per cent of water, are obtained. Another part, after passing the lawn, is pumped into a seccnd blunger. To this slip,

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which partly fills the second blunger to a predetermined depth, the required salts are added. The sodium carbonate crystals should be dissolved in hot water and the sodium silicate solution diluted before adding, to facilitate thorough and rapid mixing. The filter-press cakes are then added to this thinned slip (see p. 16) until that weight per unit volume is obtained which gives the desired density to the final casting slip.

If any scrap is to be worked over, it is added in a definite quantity and the slip allowed to blunge for some time before it is thickened by additions of the filter-press cakes.

An average time for completing a blunging in the second blunger is 4 hours; but the reader should remember that, based on dry material content, this blunger has more than double the capacity of the first, if both are the same size, for the slip contains less water. Four tons of dry material is a representative charge for a double blungerful of slip containing 30 per cent water.

2. The second method is substantially the same as that outlined in method 1. Instead of partly filling the second blunger with slip from the first blunger, water is used and the salts and subsequently the filter-press cakes are added to this water. This method is less economical than method 1 for all of the body must pass through the first blunger is used direct.

3. The body slip is blunged in the usual way and allowed to stand until the solid material has settled sufficiently to allow enough water to be decanted to bring the slip to the desired thickness. This method is very slow and has no especial merit.

PROPOSED METHOD OF PREPARING SLIP.

The method proposed eliminates the filter press and is applicable to compounded bodies containing an appreciable amount of flint and feldspar.

It is impracticable to blunge the ingredients of a body in the amount of water that is to be present in the resultant casting slip, even though salts are added to aid the disintegration of clay present. However, if the clays alone, which constitute not more than 70 per cent of the entire body, be added to a quantity of water that will give the desired proportion in the final slip their blunging is readily accomplished, the presence of the salts, which are added to the water, greatly facilitating disintegration. To the smooth clay slip obtained the flint and feldspar are added. These ingredients being in a state of fine division, mix rather readily with the blunged clay, giving a

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homogeneous body slip at a weight (per unit volume) controllable by the initial addition of water.

It is not necessary then, in changing from a plastic to a casting process, to provide additional equipment for making the slip, but on the other hand, the filter press may be discarded. One barrel of the usual double-barrel pump can be used for pumping slip to a tank from which it can feed by gravity to the lawn; the other barrel can be utilized to pump the lawned slip to the overhead storage tank, from which it is led through pipes and hose to the molds.

VARIATIONS TO BE AVOIDED.

In order to have slips which do not vary from day to day, it is essential that the following factors be kept constant.

1. Relative proportions of the ingredients making up the solid content of the slip.

The scale weights should be adjusted to counter any variation in moisture content of each ingredient, as it is used from the bin. (See fig. 5.) For example, the following moisture variations were encountered in practice in the course of three months: Flint and feldspar, ½ to 12 per cent; ball clays, 2 to 31 per cent; and china clays, 1 to 16 per cent.

2. The concentration of the salts used. (See fig. 5.)

To eliminate error in the quantity of salts added the commercial sodium carbonate should be kept in a damp, cool atmosphere, as it loses its water of crystallization (effloresces) on exposure to dry, warm air. The liquid sodium silicate should be covered to prevent evaporation of the water in which it is in "solution"; and the carbonate and silicate should each be added to the slip accurately by weight and not by volume.

To prevent the concentration of salts from varying in different parts of the same blunger, the slip must be vigorously blunged and not merely stirred. The thicker the slip the more necessary is this precaution.

3. Weight per unit volume of slip.

This furnishes a check on the water content and is conveniently taken on a pint as the unit volume.

4. Temperature of the slip.

If unusual temperature changes can not be avoided the salt additions should be adjusted to counter them.

USE OF SCRAP.

It is in the use of scrap from the casting shop that the greatest danger of wide variations arises.

Scrap that has been in contact with an absorbent mold, but has been returned to the blunger for reuse without having been com-

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pletely dried, retains a questionable amount of the salts originally added to it. Although a small quantity of salts may be "tenaciously held" by the clay colloids, the crystalline scum that appears on molds which, after having been used, are allowed to stand for several days is conclusive evidence that some salt is carried in solution as the water passes from the slip to the mold. If the scrap has been subjected to absorption by the mold, and also to the heat of the drying room, which would be the case in a piece of ware scrapped just before it was to enter the kiln, the salt content is at further variance with that of the original. The sodium silicate, having been "set" by the heat of drying, is no longer noticeably soluble in the water of the slip to which the scrap is added and therefore has no effect as a soluble salt. The sodium carbonate present, however, remains soluble. The clay gel that had not been converted to sol by the salt addition is "set" by the drying-room temperature.

In case no salts are used, wet scrap that has not been dried does not change the slip with which it is to be reblunged. But scrap that has had its gel set through drying affects the slip like such a salt as sodium carbonate.

Inasmuch as there is no feasible means of eliminating these variations, any one of which may seriously affect the casting behavior of the resultant slip, the need of eliminating as much scrap as possible is obvious.

Where scrap is reused the variations persistently encountered and difficult to eliminate render advisable and often necessary, in order to keep within the allowable limits, the checking of the final product from every blunger by viscosimeter readings.

With no variation in the proportions of the several dry ingredients, and with the same water content—that is, the same weight of ingredients per pint of slip—viscosimeter readings at any given temperature are an accurate and satisfactory check on what can be expected of the slip when used in the mold.

MOLDS.

It is the general impression that plaster molds used in casting deteriorate so rapidly that their frequent replacement must be regarded as additional expense.

Inasmuch as the amount of water to be extracted in the formation of the ware is somewhat greater in casting than in the plastic method, it seems logical that the molds should be made softer in order to obtain a more porous and absorbent structure to facilitate more rapid casting of the slip. The casting of a slip, however, is so much more a function of the character of the particular slip than of the character of the mold that it is better to construct the molds with sole regard to long service.

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Molds which are hard and almost brittle (poured with thick plaster) have been found to wear longest and "pin-hole" least readily. In fact it is often the case that wear or breakage from driving wooden wedges to tighten the bands used around the mold to hold the segments together and prevent leakage of slip, necessitates the discarding of a mold which could otherwise be used for a longer time. Two to three hundred pieces of heavy ware should be produced from a mold before imperfections on the surface due to pin-holing necessitates its being discarded.

After about fifty casts have been made there will have accumulated on the inner surface of the mold a film which will hinder somewhat the formation of the cast. This coating is no doubt some form of the sodium silicate added to the slip and should be scraped off from time to time.

DESIGN AND USE.

The design of molds for use in single-cast ware is very simple. In some of the larger single-cast pieces it may be convenient to provide a drainage from the bottom rather than to pour out the excess slip by inclining or inverting the mold. If the cast is large and rather thin, the latter method may sometimes cause the cast walls to leave the mold and collapse into the slip. If a large piece is to be cast it is well to have a mold so sectioned that its sides may be removed, leaving the piece to be handled and allowed to dry on the bottom of the mold in which it was cast.

For solid casting the molds should be so designed that no part to be cast is separated from the source or sources of the slip supply by any other part the thickness of which is less than that of the part further removed from this supply. This is well illustrated by the following example.

In casting a sink, as shown in figure 6, the slip is admitted at *a*, preferably at a place which will subsequently be punched out to furnish a spud hole or other permanent opening in the piece of ware. The sides *c*, being relatively thin, will cast solid before either the bottom *b* or the rim *d*. The bottom will continue casting until it has cast solid, but the rim *d*, being shut off from the supply of slip at *a*, will not cast solid. If the rim must be solid, a second slip inlet must be provided at this particular place.

If the rim *d* may be left hollow, it is necessary to drain out the inclosed slip to prevent cracking; and if the center left uncast is very small, air pressure (blowing with the breath may do) may have to be applied to remove the remaining slip. For draining, two openings are made, one an outlet for the slip, the other an inlet for air. To prevent the slip from casting shut the opening *a* through the plaster, brass tubing is set in when the plaster mold is poured.

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If a core mold is to be over 3 inches thick it is advisable, in order to facilitate its drying and reduce its weight, to make it hollow as shown in figure 6.

Molds designed to make a part which is to be set into an assembly mold to be overcast should be made enough undersize to give the part about one-eighth inch clearance from the walls of the assembly mold. This space allows the slip to form a cast layer that conceals any irregularities of contour at the places where two pieces join.

Molds are most easily cleaned immediately after removal of the cast and should be gone over with a cloth at this time. They should not be placed on or near steam pipes for drying unless care be taken to remove them before they have become entirely dry. An absolutely dry mold will not, when filled with slip, deliver a cast piece in

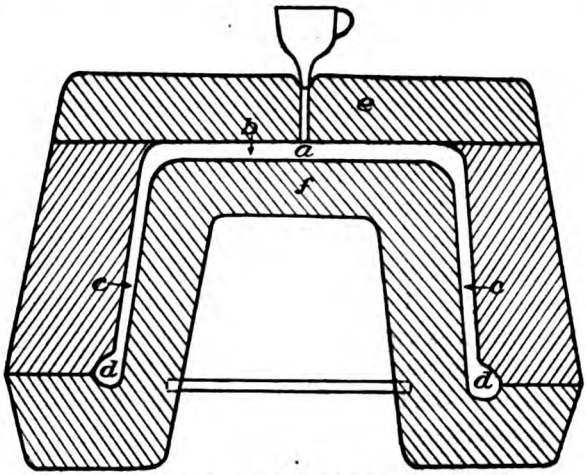

FIG. 6.—Cross section of sink and of core mold.

a condition to facilitate as even and safe drying as will one which is just moist enough to prevent the tendency to form a dry shell on that part of the ware adjacent to the mold's surface.

It is only in making the lighter wares that molds are used more often than once each day. In casting some thin tablewares as high as 10 casts are made daily from each mold, but in this case the molds are subjected to intensive drying, a treatment that, as has been pointed out, would be inadvisable in connection with heavier casts.

MAKING OF WARE.

The plaster molds are filled from pouring vessels or from hose, care being taken not to entrap any air.

In the case of a single cast it is easy to tell by the eye, or feel, just when the cast has reached the desired thickness. The excess slip is

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then drained either by inverting the mold or drawing it from an opening in the bottom of the mold. As soon as the cast has sufficiently stiffened and will leave the mold it is removed from the mold, if a small piece with no undercuts, but if it is large or is complicated in design, all sections of the mold except the bottom one are taken away from it.

Any openings left in the cast piece for drainage of slip are plugged with plastic clay. If, however, the plugging of an opening would inclose an air pocket, as in the hollow rim of the piece shown in figure 6, another smaller opening must be made, usually with a wire, to allow escape of the inclosed air when it expands in the biscuit and glost heats, to prevent rupture of the piece in the kiln.

In solid casting the cast is complete when the slip no longer recedes down the sides of the funnel, which serves as a reserve reservoir to feed slip into the molds.

Take, for example, the cast shown in figure 6. After casting is complete, the cast is allowed to stand in the molds for an hour or two, the time varying with the thickness of the cast and the condition of the molds, until the piece has stiffened and will leave the mold. Then, with the piece still in its inverted position, the bottom section *e* of the mold is removed and a hole, which should be small if it is to be reclosed or of the size required to admit a spud or other attachment in the finished article, is punched or cut through the bottom of the piece at *a*. The bottom section of the mold is then replaced and the whole is righted to permit the core *f* to be vertically withdrawn. Air admitted at *a* prevents the bottom from "sucking up" with the core. Dusting of the core with some dry pulverized body scrap will facilitate its removal.

With the piece in its upright position, the side molds are removed as soon as the piece can stand, so they can better dry for reuse on the next day. Extra bottom molds are provided so the piece may be handled and allowed to dry on the bottom mold to which it was cast.

Cast articles must be finished within a shorter period of time after formation than is practiced with plastic formed ware. Owing to the reduced gel content and consequently more "open structure" of the former, they dry much more quickly. A heavy piece can be trimmed and roughly finished in the afternoon of the same day on which it was cast.

Soluble salts are carried in solution by the water which remains in the pores of the cast after it is removed from the mold. As the piece completes its drying on the dry racks or the stillyards, these salts are carried to the surface of the ware and there deposited as the water evaporates. Unless these surface deposits, sometimes invisible and sometimes resembling frost, are removed before the piece is fired, there results on the burned article a glassy coating of

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material more fusible than the body of the ware. For this reason it is necessary, especially in heavy wares, in which the quantity of water evaporated and of salts carried to the surface is greatest, to clean the casts after they have completely dried.

BURNING OF WARE CONTAINING SOLUBLE SALTS.

The glassy coating on the surface of the burned biscuit piece, which in an aggravated case is often blistered, has often influenced the burning of cast wares which were improperly finished in the unburned state. Inasmuch as the tendency to blister is reduced with reduced heat treatment, an attempt to obviate blistering in this way may easily lead to underfired anad easily dunted (ruptured by the intensifying of internal stresses from temperature changes) ware.

In properly finished ware, however, this blistering defect is not troublesome, and there is no reason for not being able to fire a cast piece to the same heat as would be employed if the piece contained no salts.

A manufacturer of hotel porcelain, burned to cone 10, who makes ware both by the plastic and casting processes, found that in those parts of the kiln which had received a heat treatment slightly under the normal the cast pieces would be vitrified, whereas those pieces which had been jiggered showed evidence of underfiring. No difference was evidenced in the overfiring, both cast and jiggered pieces being affected alike.

Inasmuch as more salts are required in preparing a slip of higher clay content, the blistering, underfiring, and dunting above referred to are more often encountered in those wares of higher clay contents.

PUBLICATIONS ON MINERAL TECHNOLOGY.

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